

Transpiration and Photosynthesis of the Olive Tree: a Model Approach

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Abstract

Preliminary results of simulation by the RATP (Radiation Absorption, Transpiration and Photosynthesis) model on olive tree are presented. At leaf level, Jarvis' stomatal conductance (g_s) model and Faquhar's photosynthesis (A) model were parameterised on 2-year-old plants under controlled conditions. At canopy level the spatial distribution of leaf area density of a 31-year-old tree was described for simulating whole tree transpiration (E_p) by RATP. Simulated E_p values were compared with sap flow measurements. At leaf level, results showed a realistic behaviour both of g_s and A . At the canopy level, the simulated E_p values agreed well with the E_p determined from sap flow measurements. The simulated values of A by the RATP model were not validated with field measurements. A better agreement of E_p estimates could be expected, provided that the architecture of the canopy and the sap flow are characterised more precisely.

INTRODUCTION

Rational orchard management requires comprehensive information about tree functioning. A detailed knowledge of water use and carbon assimilation by the plant as a function of the environmental conditions is crucial for optimising irrigation, tree formation and pruning. Reliable and robust models of transpiration and photosynthesis are, in fact, of great interest for optimising both orchard design and management.

Tree orchard canopies are most complex than those of most annual agricultural crops, so "big leaf" models are inadequate to describe neither transpiration nor photosynthesis. The RATP model was developed for simulating the spatial distribution of transpiration and photosynthesis within complex canopies (Sinoquet, 2000). Briefly, the model uses a 3D representation of the canopy as an array of 3D cells, each one characterised by its leaf area density. The canopy is treated as a turbid medium where direct and diffuse radiation are considered as directional. The fraction of sunlit leaf area is computed from the gap frequency in the sun direction. Stomatal conductance is computed following the Jarvis approach (1976) as a function of PAR radiation, water vapour pressure deficit, leaf temperature and soil water content. Photosynthesis rates are simulated according to Farquhar et al. (1980) as the version proposed by Leuning (1995). Leaf temperature, transpiration and photosynthesis rates, for both sunny and shaded leaves, are derived from an energy balance.

MATERIALS AND METHODS

The experiments were carried out at the experimental farm of the *Instituto de Recursos Naturales y Agrobiología* at Coria del Río near Seville in Spain (37° 17' N, 6° 3' W, elevation 30 m). In 1999, spatial distribution of the 3D cells in a 31-year-old olive tree was determined by the point quadrats method. The distribution of leaf area density at different locations in the canopy was evaluated by a cubic volume built with metal rods. In addition, tree leaf area was estimated from the allometric relationship with the diameter of the shoots. Soil water content was measured with a neutron probe, in four access tubes at 0.5, 1.5, 2.5 and 3.5 m from the tree trunk. Weather variables were measured with an automatic weather station located some 50 m away from the experimental tree. Seventy 2-

year-old olive trees grown in pots were used to calculate the parameters related to Jarvis' stomatal conductance model and Farquhar's photosynthesis model. The response curves of g_s to changes in the environmental variables and the A/C_i curves were obtained under controlled conditions in a fitotron chamber with a Li-6400 (Li-Cor, Ne, USA). Survey measurements of g_s and A , made from March to August 1998 both in irrigated and non-irrigated 30-year-old trees, were used for validating the leaf models. The transpiration of the tree where spatial distribution of leaf area had been studied, was estimated from sap flow measurements using the compensation heat pulse (CHP) technique (Green and Clothier, 1988). Three sets of CHP probes were installed in each of the two main branches of the tree.

RESULTS AND DISCUSSION

The relations between measured and simulated g_s and A are shown in Fig. 1. The models simulate well the daily evolution of both variables for a wide range of soil water content. The marked stomatal control on transpiration of the olive tree (Fernández et al., 1997) makes crucial to characterize appropriately the response of the stomata to the main environmental variables. In addition, the close relation between g_s and A makes the photosynthesis model be very sensitive to the stomata behaviour. Therefore, the reliability of the stomatal conductance model is crucial.

A comparison of the diurnal course of E_p values estimated by the model with those determined from the sap flow measurements in each main branch of the tree is shown in Fig. 2. The model predicted 86 % of the total E_p as estimated by the CHP technique. Higher values of transpiration in branch 1 were due to its greater leaf area (21.1 m²) and probably to its orientation to southwest. Branch 2 was oriented to the northeast and its leaf area was estimated to be 9.1 m². Fig. 3 shows the high variability found between the different sets of probes, both in branch 1 and in branch 2, which suggests that more probes could have been necessary for an accurate determination of the transpiration of a mature olive tree. The high variability of the conductance system of the olive tree was pointed out by Fernández y col. (1998). As expected, the tree photosynthesis was mainly supported by sunny leaves (Fig. 4). In clear days such as DOY (day of year) 313 and 314, up to 5.5 g C h⁻¹ were fixed in sunny leaves, while less than half was done in the shaded ones, despite the sunny and shaded area being in the same proportion at midday. To our knowledge this is the first time that the whole photosynthesis of a mature olive tree has been estimated. Pruning practices in the experimental area keep the crowns of the trees very opened which avoids marked irradiance gradients within the canopy, as well as a high proportion of shaded leaves. The model can be used, for instance, to compare the effect of different leaf area densities in the trees or different tree densities in the orchard in terms of water use efficiency. Although the obtained results are satisfactory, a better agreement between simulated and actual values can be expected, provided the tree architecture is characterised more precisely. Variability also arises from error in the estimation of E_p by the CHP technique. In addition, more work is needed for validating model simulations of spatial distribution of radiation within the crown of the tree and photosynthesis rate at branch scale.

Literature Cited

- Farquhar, G.D., Von Caemmerer, S. and Berry, J.A. 1980. A biochemical model of photosynthetic CO₂ assimilation in leaves of C₃ species. *Planta*, 149, 78-90.
- Fernández, J.E., Moreno, F., Giron, I.F. and Blázquez, O.M.. 1997. Stomatal control of water use in olive tree leaves. *Plant and soil*, 190, 179-192.
- Green, S.R. and Clothier B.E. 1991. Water use of kiwifruit vines and apple trees by the heat-pulse technique. *J. Exp. Bot.*, 39, 115-123.
- Jarvis, P.G. 1976. The interpretation of the variations in leaf water potential and stomatal conductance found in the field. *Phil. Trans. R. Soc. London, Ser. B*: 273, 593-610.
- Leuning, R. 1995. A critical appraisal of a combined stomatal-photosynthesis model for C₃ plants. *Plant, Cell and Environment* 18,339-355.

- Fernández, J.E., Palomo, M.J., Díaz-Espejo, A., Girón, I.F. y Moreno, F. 1998. Measuring sap flow in olive trees: potentialities and limitations of the compensation heat-pulse technique. Proc. of the 4th Workshop on Measuring Sap Flow in Intact Plants. Zidlochovice, Czech Republic, 3-4 November, 16.
- Sinoquet H., Le Roux X, Ameglio T. and Daudet F.A. 2000. Modélisation de la distribution spatiale du microclimat lumineux, de la transpiration et de la photosynthèse: application à un arbre isolé. In: Fonctionnement des peuplements végétaux sous contraintes environnementales. Paris (France), 20-21 January 2000. Ed. INRA, Paris.

Figures

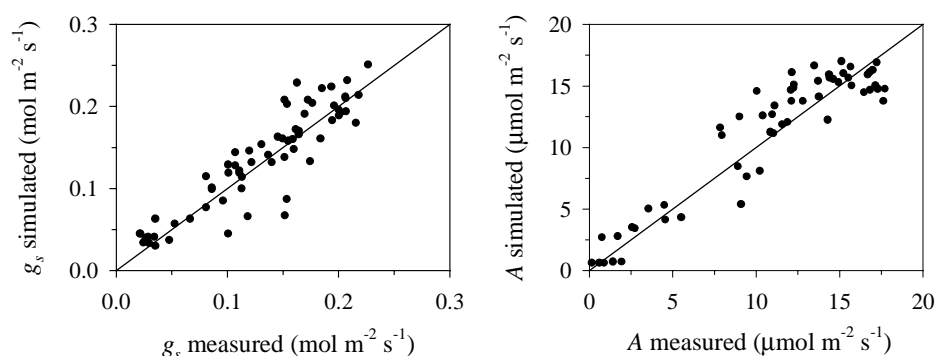


Fig. 1. Relationships between measured and simulated stomatal conductance (g_s) and photosynthesis (A). Each point represents the average of 10 leaves. Line 1:1 is also shown.

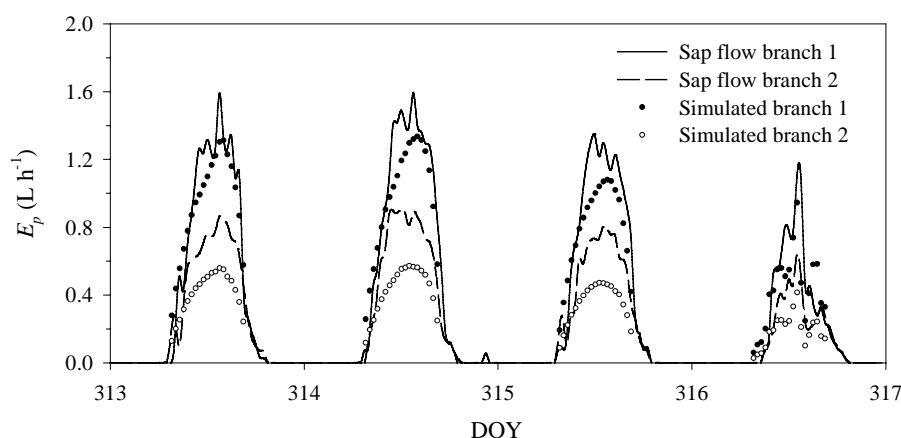


Fig. 2. Comparison between the transpiration rate (E_p) estimated from sap flow measurements and that simulated by the RATP model. DOY = day of year.

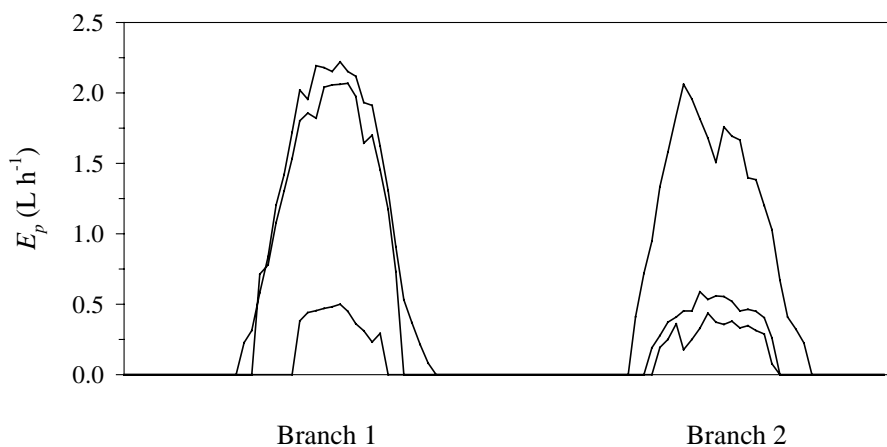


Fig. 3. Transpiration rate (E_p) estimated on 314 by each CHP probe in the two branches of the experimental tree.

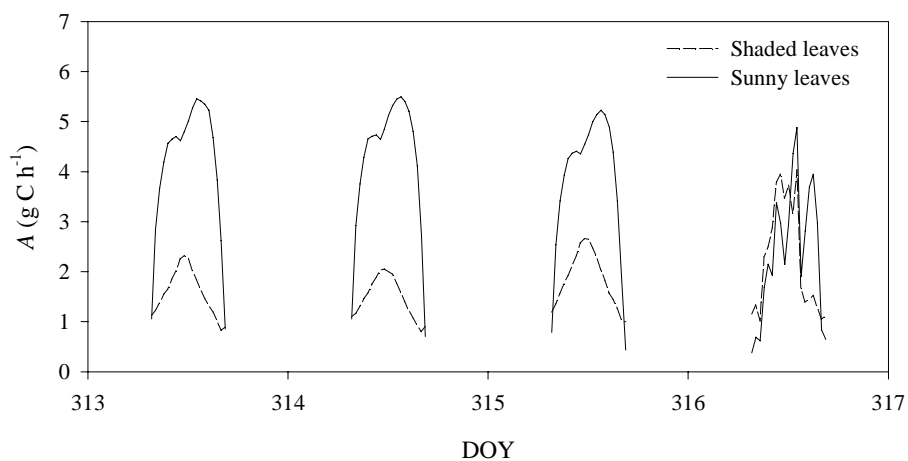


Fig. 4. Daily photosynthesis (A) simulated for both the sunny and the shaded canopy area of the experimental tree. DOY = day of the year.